WATER SOLUBLE SUBSTANCES IN TERRESTRIAL ANTARCTIC PLANTS AND MICROBES

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ABSTRACT

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Many Antarctic plants and microbes have been found to contain large amounts of water-soluble substances. These decompose and release mineral nitrogen at differing rates (algae, including cyanobacteria > lichens > mosses). More mineral nitrogen is produced at high than low moisture levels during incubations at 4°C. Results are discussed in relation to soil colonization and the environmental conditions prevailing in two climatically different areas of Antarctica: maritime and continental regions.

KEYWORDS: Antarctica - cryptogams - water soluble substances - nitrogen - decomposition - colonization.

INTRODUCTION

The terrestrial biota in Antarctica is subjected to freeze-thaw and wet-dry cycles during the growing season. At 77°S in the Ross Sea regions of continental Antarctica, these cycles are frequently imposed over the prevailing dry cold environmental conditions, whereas at between 60-65°S on islands in maritime Antarctica, they frequently occur over moist cold conditions.

The New Zealand Antarctic Research Programme and the British Antarctic Survey have been examining, since 1981, the factors and processes involved in the colonization of largely ahumic exposed mineral soils (fellfields) by microbes, plants and invertebrates. Water-soluble nutrients and water availability, rather than temperature, are considered to be among the most important factors influencing successful colonization (Tearle 1987).

Tearle (1987) found that freeze-thaw cycles caused cellular damage to Signy Island mosses, lichens and algae, resulting in the leaching of cellular contents. He found that sugars and polyols (cryoprotectants) occurred in mosses, lichens and algae, and that their concentrations showed seasonal variation. Wynn-Williams (1985) has suggested that leachates from temperature-damaged cells may assist the formation of microbial biofilms. These consist of mucigel-embedded cyanobacteria, other bacteria, and algae. Such assemblages probably help to stabilize and prepare the mineral soil surface for the germination of moss spores.

Tearle's work was on ethanol-soluble extracts but there appears to be no information on the amounts, nature and decomposition of water soluble substances from Antarctic terrestrial biota. This present paper examines the amounts and nitrogenous nature of water soluble substances derived from plants and microbes sampled from mineral soils under the contrasting environmental conditions existing in maritime and continental Antarctica. It also examines the mobilization of nitrogen in freeze-dried water extracts of these organisms under different water regimes.

MATERIALS AND METHODS

Figure 1 and Table 1 show the localities where samples were collected. Antarctic terrestrial vegetation is generally quite sparse so in order to preserve this unique biota only small samples (< 5g) were collected.

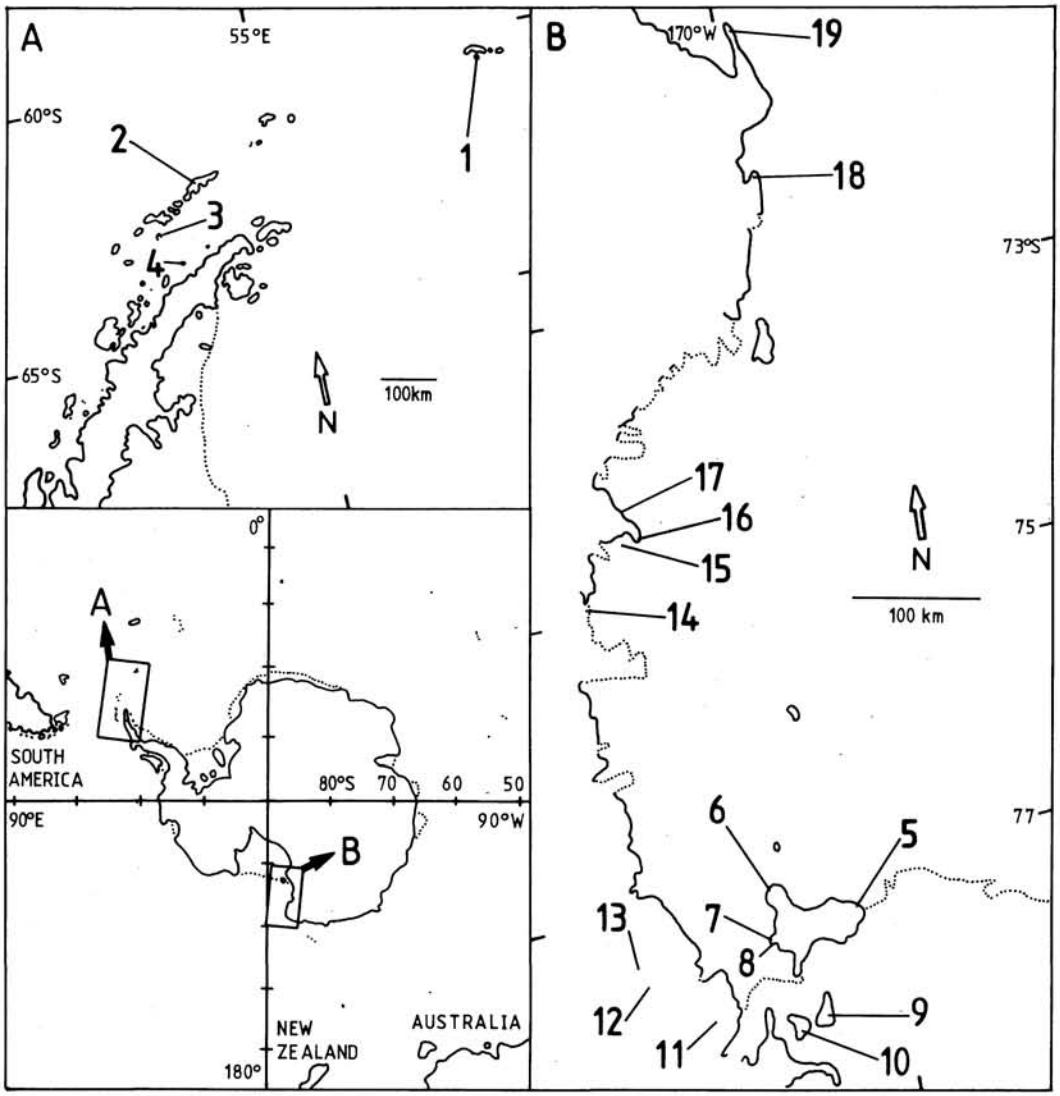

Figure 1. Map showing locations of sampling sites in (A) maritime Antarctica, and (B) the Ross Dependency. 1 = Signy Island, 2 = King George Island, 3 = Deception Island, 4 = Astrolabe Island, 5 = Cape Crozier, 6 = Cape Bird, 7 = Cape Royds, 8 = Cape Barne, 9 = White Island, 10 = Black Island, 11 = Garwood Valley, 12 = Taylor Valley, 13 = Wright Valley, 14 = Inexpressible Island, 15 = Terra Nova Bay, 16 = Cape Washington, 17 = Edmondson Point, 18 = Cape Hallett, 19 = Cape Adare.

Many genera or species were common to different localities, and for convenience some samples were combined. Cyanobacterial mats were dominated by species of Oscillatoriaceae with a lower abundance of other cyanobacteria, chlorophytes and diatoms. These mats were categorized into (a) fresh, hydrated and (b) old, desiccated materials - the latter comprised brittle material collected in areas which had received no meltwater for at least one year. *Nostoc commune* samples were combined into two collections: the first consisted of material occurring on soil surfaces, while the second contained material obtained from cryoconite pools on glaciers.

Organisms	Site conditions	Locality numbers (see Fig. 1)	Collection dates
MICROBES, INCLUDING ALGAE			
*Cyanobacteria (fresh)	mats on moist soils & in small streams	all except 2 & 16	Nov '78, '80, '82, '85, '86; Mar '88
* Cyanobacteria (old)	mats on dry soil surface and dried streams	3,4,5,6,7,9,11,12,16,17	Jan '78, '88; Nov '82, '85, '87
Prasiola crispa	green foliose mats on guano enriched wet rocks	1,3,4,5,6,7,14,17,18,19	Jan '80, '83, '86, '88 Mar '88
Prasiola calophylla	green filaments in small streams	11,3	Jan '87; Dec '84, '88
Nostoc commune	brown-green sheets on moist soils & in cryoconite pools	3,4,6,7,8,10,11,12,13	Nov '78, '81, '83, '87 Mar '88
Urospora sp.	green filaments on guano enriched wet soils	6	Dec '83
Binuclearia sp.	green-brown filaments in small river	11	Jan '87
Green & Red snow algae	snowdrifts & glaciers	1,3,4	Dec '87; Mar '88
LICHENS			
Usnea antarctica	fruticose growth on dry rock surfaces	1,3,4,7,16,17	Dec '85, '86, '87; Mar '88
Usnea fasciata	fruticose growth on dry rock surfaces	1,3	Dec '87; Mar '88
Stereocaulon sp. *Sphaerocaphorus* sp. *Himantormia lagubris* *Rhizocarpon* sp. *Cladonia* sp. *Placopsis* sp. *Ochrolechia* sp.	fruticose & crustose growths on dry rock surfaces	1,3,4	Dec '87 Mar '88
Xanthoria mawsonii	crustose growth on dry rock surfaces	1,3,4,5,7,11,14,16,17, 18,19	Nov '81, '85; Jan '87 Dec '87; Mar '88
Umbilicaria aprina	fruticose growth on dry rock surfaces	1,4,7,11,14,16	Dec '83; Nov '85 Jan '87; Mar '88
Lecanora melanophthalma	crustose growth on dry rocks and wooden spars	3,5,7,11,13,17	Dec '83; Nov '85 Jan '87; Dec '87
Lepraria sp.	crustose growths on dry moss cushions	3,17	Dec '85, '87
Buellia sp.	crustose growths on dry rocks	3,7,11,14	Nov '81; Dec '85, '87 Jan '87
Physcia caesia	crustose growth on dry rocks	3,17	Dec '85; Jan '88
MOSSES			
Bryum pseudotriquetrum	cushions on wet & dry soils	6,7,11,12,13,17,18,19	Nov '81; Dec '83, '85 Jan '84, '87
Sarconeureum sp.	cushions on damp soils	11	Jan '87
Brachythecium sp. *Polytrichum* sp. *Drepanocladus* sp. *Andreaea regularis*	cushions on moist & dry soils	1,3	Dec '80, '85, '87 Mar '88
GRASS			
Deschampsia antarctica	erect brown leaves on live plants on moist soils	1,2	Feb '83; Mar '88

*Cyanobacterial mats dominated by *Phormidium* spp.

Table 1. Sampling locations and composition of samples.

Samples were air dried in the field and stored at 0°C in plastic bags until laboratory analysis, usually within 2 months of collection. With the exception of intact materials (see below) all samples were ground to <1 mm and subsamples taken for moisture (105°C, 24 h), ash (550°C, 4 h) and nitrogen determinations by the micro Kjeldahl procedure.

Intact samples used in extraction experiments were prepared as follows. Discs (1 cm diameter) were taken, using a cork borer, from *Prasiola crispa*, *Nostoc commune* and *Xanthoria mawsonii* growths collected from Cape Bird, Garwood Valley and Cape Royds respectively. Individual stems (2 cm long) were dissected from *Bryum pseudotriquetrum* and *Andreaea regularis* moss cushions occurring at Cape Bird and Signy Island respectively. Similar sized (3 cm height) fruticose colonies of *Usnea antarctica* were cut from rock surfaces at Capes Royds and Washington, and from Deception and Signy Islands.

EXTRACTION OF WATER SOLUBLE SUBSTANCES

Ground and intact samples were treated as follows. Duplicate 1 g samples (air dry basis) were extracted for up to 7 days without shaking in 50 ml centrifuge tubes containing 30 ml distilled, deionized water and 0.2 ml chloroform to prevent microbial growth during the extraction. Tubes were then centrifuged and the clear supernatants freeze-dried. Tubes containing sample residues were frozen for 12 h followed by a 4 h thaw period before being re-extracted with chloroform water as before. The samples were then subjected to a gentle drying air stream for 24 h before being re-extracted with chloroform water. In this way sample residues were subjected to 3 freeze-thaw and 2 wet-dry cycles, each cycle being followed by a 7 day extraction period with chloroform water. All manipulations were performed at 4°C. Following the final extraction, residues were oven dried and then cooled in a desiccator before reweighing and grinding. Subsamples were then taken for ash and nitrogen determinations.

MOBILIZATION OF NITROGEN FROM FREEZE-DRIED PLANT AND MICROBIAL WATER EXTRACTS

In order to obtain sufficient amounts of water-soluble substances for mobilization experiments it was necessary to combine extracts from similar species, or from taxa collected at different locations (Table 2). 0.1 - 0.4 g of extract was mixed with 5 g ignited coarse sand and 0.1 ml microbial inoculum, prepared from a shaken *Bryum* suspension (1 g *Bryum* : 100 ml water). Distilled water was then added to bring the moisture content of one set of duplicate flasks to 5% and another set to 20% (dry wt basis). These moisture contents were

	Extract composition	Location
C	Cyanobacterial mats (fresh)	Capes Bird, Royds & Crozier; Garwood & Taylor Valleys
C	Cyanobacterial mats (old)	Capes Bird & Crozier; Garwood, Taylor & Wright Valleys
S	*Prasiola crispa*	Capes Bird, Crozier, Hallett & Adare; Inexpressible, Deception, Astrolabe & Signy Islands; Garwood Valley
S	*Prasiola calophylla*	Garwood Valley
S	*Nostoc commune*	Capes Bird & Royds; Garwood & Taylor Valleys; Edmondson Point
C	Lichen mixture*	Capes Royds & Crozier; Garwood Valley; Edmondson Pt; Deception & Signy Islands
C	Moss mixture**	Capes Bird, Royds & Hallett; Garwood & Taylor Valleys; Edmondson Point; Deception & Signy Islands

C = combination of species, S = single species.

* *Xanthoria* sp., *Lecanora* sp., *Buellia* sp., *Umbilicaria* sp., *Usnea* sp., *Lepraria* sp., *Physcia* sp. (see Table 1).

** *Bryum* sp., *Polytrichum* sp., *Drepanocladus* sp., *Andreaea* sp. (see Table 1).

Table 2. Origins of samples used to prepare freeze-dried water extracts for decomposition experiments (Table 5).

selected because they are commonly found in Antarctic fellfield soils during late spring and summer. Each duplicate set of flasks was capped with thin polyethylene film and incubated in the dark at 4°C for up to 40 days.

After this time mineral nitrogen (N) present in these sample flasks was determined in KCl extracts by steam distillation in the presence of MgO and Devarda's alloy, according to Bremner's method (Bremner 1965). The mineral-N present in control flasks at day 0 was subtracted from that present in incubated flasks to give the amount of mineral-N produced by microbial action. This is expressed as a percentage of the initial total sample N minus initial mineral-N.

CHEMICAL NATURE OF WATER SOLUBLE SUBSTANCES

Extracts were analyzed by thin layer chromatography for sugars, organic acids and amino acids after passage over cation and anion exchange resins (Nykvist 1963, Smith 1976). Nitrogen distribution analyses of whole samples and freeze-dried extracts were performed as described by Greenfield (1979).

RESULTS

Many samples, particularly those from the Ross Dependency, were found to contain large amounts of wind-blown or water-borne mineral material. Results for weight losses are presented on an ash free basis. Since many samples collected in widely different locations were of a similar species, e.g., *P. crispa*, or contained similar microbial communities, e.g., cyanobacterial mats, the results for these samples have been combined, and means plus ranges given.

For all algal samples, excepting 'old' samples, approximately 33% (18-48%) of the weight and 35% (11-53%) of the nitrogen were removed by the leaching procedure. For lichens approximately 14% (5-39%) of the weight and 27% (17-40%) of the nitrogen were removed under similar leaching conditions whilst in the case of mosses, approximately 16% (9-27%) and 22% (18-26%) of the weight and nitrogen respectively were removed (Table 3).

If the results for weight and nitrogen loss from ground tissues are compared with those from intact tissues (Table 4) then it is apparent that for the two algae and the lichen *Xanthoria*, the bulk of weight and nitrogen loss occurred during the first extraction period with water, and that 2 or 5 freeze-thaw / wet-dry cycles had little influence in increasing these amounts over and above those released in the absence of such treatments. After 35 days, in the case of *Usnea* and both mosses, approximately 50% less weight loss and nitrogen loss had occurred compared to those values obtained over a similar period for ground tissues with or without freeze-thaw / wet-dry cycles (Table 3).

Considerably more nitrogen mobilization occurred from freeze-dried extracts of microbial tissues than from combined lichen and moss extracts after 40 d incubation at 4°C (Table 5). More nitrogen was mobilized after this time in samples held at 20% moisture level than at 4%. Under both moisture regimes slightly more N mobilization occurred from fresh than old cyanobacterial mat extracts.

Qualitative chromatographic analysis of the freeze-dried extracts revealed in all samples the presence of glucose, ribose, fructose, alanine, arginine, asparagine, glycine, leucine, lysine, proline, serine, valine, and aspartic, glutamic, fumaric, succinic and malic acids. In addition, arabinose was detected in moss extracts, and glucosamine and galactosamine in lichen extracts.

Nitrogen distribution analyses of several microbial and plant species indicated that the bulk of the nitrogen present was proteinaceous (50% of the N in these samples occurred as alpha-amino-N (Table 6)). Earlier work (Greenfield 1972, 1979) indicates that a substantial fraction of hydrolyzate-NH_4-N and hydrolyzable unidentified nitrogen (HUN) is derived from amide-N and non alpha-amino-N respectively. This suggests that 70-80% of original sample-N is in the form of proteins. A similar line of reasoning can be invoked for the nitrogenous compounds present in freeze-dried extracts. Following acid hydrolysis the alpha-amino-N values increased substantially with a concurrent lowering of the HUN values compared to those in non-hydrolyzed extracts (Table 6). Water extracts therefore contained proteins in addition to free amino acids. Lichens contained 8% of their nitrogen in the form of hexosamines probably derived largely from fungal cell-wall chitin.

Organisms	No. of samples	% initial total nitrogen $\bar{x}$	(range)	S.D.	% weight loss $\bar{x}$	(range)	S.D.	% nitrogen loss $\bar{x}$	(range)	S.D.
MICROBES & ALGAE										
Cyanobacterial mats (fresh)	22	3.57	(1.92-5.52)	1.06	18	(8-33)	6.1	26	(15-47)	7.8
Cyanobacterial mats (old)	12	3.11	(1.51-4.27)	0.8	7	(2-13)	3.17	11	(8-13)	1.71
Prasiola crispa	43	6.98	(3.21-9.86)	1.72	25	(11-33)	4.48	30	(21-42)	5.7
Prasiola calophylla	6	6.42	(5.6-6.81)	0.3	39	(23-46)	8.38	26	(16-33)	6.94
Nostoc commune (soil)	27	4.86	(3.38-7.03)	0.69	23	(11-50)	8.16	35	(18-71)	10.04
Nostoc commune (cryoconite)	4	5.57	(4.37-6.82)	1.09	48	(43-55)	5.38	30	(29-34)	2.51
Urospora sp.	2	6.40	(5.32-7.49)	1.52	42	(40-43)	2.23	53	(49-57)	5.65
Binuclearia sp.	3	4.82	(4.34-5.11)	0.41	38	(32-43)	5.56	42	(36-48)	6.0
Green snow algae	3	9.08	(8.72-9.27)	0.29	32	(29-38)	4.95	38	(32-44)	6.0
Red snow algae	5	7.51	(5.81-8.27)	0.97	31	(22-41)	7.46	46	(29-60)	13.6
LICHENS										
Usnea antarctica	7	0.90	(0.54-1.15)	0.18	15	(8-21)	4.0	27	(22-31)	3.36
Usnea fasciata	2	0.71	(0.67-0.74)	0.1	11	(10-11)	0.71	29	(27-31)	4.0
Stereocaulon sp.	2	1.39	(1.17-1.62)	0.3	10	(8-11)	2.12	21	(21-22)	0.71
Sphaerocaphorus sp.	3	0.41	(0.32-0.46)	0.07)	9	(8-9)	0.58	20	(15-28)	6.8
Himantormia sp.	4	0.67	(0.61-0.72)	0.05	8	(6-9)	1.41	32	(29-36)	3.0
Rhizocarpum sp.	2	1.57	(1.32-1.82)	0.34	16	(15-16)	0.71	27	(20-33)	8.6
Cladonia sp.	2	0.72	(0.69-0.76)	0.10	9	(8-9)	0.71	17	(16-17)	0.71
Placopsis sp.	3	0.42	(0.34-0.54)	0.09	12	(9-16)	3.6	20	(15-28)	6.8
Ochrolechia sp.	4	0.50	(0.48-0.53)	0.04	9	(7-12)	2.2	19	(14-26)	5.3
Umbilicaria aprina	8	1.23	(0.95-1.53)	0.2	14	(10-20)	3.25	39	(37-43)	2.2
Lecanora melanophthalma	7	1.79	(1.04-2.69)	0.56	15	(9-28)	2.04	26	(11-40)	11.0
Lepraria sp.	2	1.24	(1.09-1.39)	0.21	12	(11-12)	0.7	17	(16-17)	0.7
Buellia sp.	12	1.15	(0.73-1.57)	0.27	28	(16-33)	4.87	40	(38-51)	3.58
Physcia caesia	3	1.71	(0.81-2.63)	0.91	5	(3-8)	2.6	30	(29-30)	0.71
Xanthoria mawsonii	9	2.99	(2.15-3.91)	0.55	39	(32-46)	4.92	38	(31-51)	8.9
MOSSES										
Bryum pseudotriquetrum	31	2.17	(0.54-3.02)	0.7	27	(8-36)	6.6	26	(15-44)	7.7
Sarconeureum sp.	3	1.61	(1.12-2.23)	0.56	14	(12-15)	1.58	18	(9-27)	9.03
Brachythecium sp.	7	1.76	(0.55-2.16)	0.58	13	(9-22)	5.1	20	(17-31)	4.86
Polytrichum sp.	11	1.63	(0.93-3.16)	0.75	17	(9-30)	7.25	21	(14-27)	4.48
Drepanocladus sp	9	1.73	(1.01-3.10)	0.69	18	(6-25)	6.02	23	(17-31)	4.4
Andreaea regularis	5	1.22	(0.85-1.46)	0.21	9	(6-16)	4.2	23	(14-29)	5.5
GRASS										
Deschampsia antarctica	3	3.12	(2.73-3.61)	0.44	25	(23-27)	2.12	46	(32-56)	12.6

Table 3. Mean weight loss (ash free basis) and nitrogen loss following 35 days water extraction of ground samples of Antarctic biota.

DISCUSSION

This study shows that many Antarctic terrestrial microbes, lichens and plants, collected from widely different locations, under markedly different climatic conditions, contain water soluble substances. This extends Tearle's (1987) survey in which he found that ethanol extraction removed 16, 19, 4, 20 and 6%, respectively, of the total mass of *Usnea*, *Himantormia*, *Andreaea*, green, and red snow algae. The use of ground samples in both Tearle's and the present study probably results in maximal values for soluble substances. However, considerable amounts of these substances were removed from intact tissues after 7 days water extraction without freeze-thaw cycles. Some investigators (e.g., Crittenden 1981, Farrar 1976 and Gupta 1977) have shown, but not quantified, that

Days extraction / freeze-thaw wet-dry cycles			7/0			7/2			35/0			35/5*		
Organisms	No. of samples		$\bar{x}$	(range)	SD	$\bar{x}$	(range)	SD	$\bar{x}$	(range)	SD	$\bar{x}$	(range)	SD
Prasiola crispa	5	% wt loss	18	(13-25)	2.17	20	(13-25)	5.81	23	(12-31)	7.12	23	(15-35)	7.6
		% N loss	22	(17-26)	4.09	21	(19-24)	1.93	31	(19-38)	7.14	28	(19-36)	6.54
Nostoc commune	3	% wt loss	16	(9-25)	8.1	15	(11-20)	4.5	21	(14-36)	12.7	26	(17-43)	15.0
		% N loss	30	(14-39)	13.2	27	(12-40)	14.1	36	(18-48)	16.3	35	(26-42)	13.0
Bryum pseudotriquetrum	4	% wt loss	6	(3-11)	3.6	7	(3-8)	2.4	15	(10-30)	10.0	18	(9-31)	9.5
		% N loss	9	(8-10)	0.8	7	(7-8)	0.57	16	(10-33)	11.3	18	(6-34)	12.1
Andreaea regularis	3	% wt loss	3	(3-4)	0.71	3	(2-3)	0.71	5	(3-7)	2.0	4	(3-7)	2.3
		% N loss	9	(3-14)	5.5	9	(5-16)	5.87	12	(8-15)	3.5	13	(10-15)	2.9
Usnea antarctica	5	% wt loss	6	(3-11)	3.4	5	(3-12)	3.96	9	(8-11)	1.65	7	(7-8)	0.71
		% N loss	12	(7-18)	4.82	14	(5-16)	4.92	15	(11-21)	4.3	15	(11-21)	4.2
Xanthoria mawsonii	6	% wt loss	24	(13-33)	7.0	24	(11-32)	10.0	36	(26-39)	5.2	40	(28-43)	5.7
		% N loss	27	(11-36)	8.1	28	(14-36)	7.7	39	(24-50)	8.9	37	(22-39)	10.1

* 35/2 for N loss

Table 4. Mean weight and Nitrogen losses (ash free basis) following water extraction of samples of intact Antarctc biota.

Organisms	No. of samples	% Nitrogen mobilized 4% moisture[a] $\bar{x}$	(range)	SD	20% moisture $\bar{x}$	(range)	SD
Cyanobacterial mats (fresh)	4	8	(6-10)	1.6	22	(19-27)	4.2
Cyanobacterial mats (old)	4	2	(0-3)	1.0	18	(15-21)	2.5
Prasiola crispa	3	14	(12-19)	4.1	35	(29-41)	6.0
Prasiola calophylla	3	6	(2-12)	5.2	20	(18-23)	2.6
Nostoc commune	6	11	(10-16)	2.5	19	(17-26)	3.4
Lichen* composite	2	5	(3-7)	2.8	8	(4-12)	5.6
Moss* composite	2	1	(0-2)	1.0	4	(0-8)	4.0

* mixture of freeze-dried extracts derived from different species (see Table 2).

[a] % dry weight

Table 5. Percentage nitrogen mobilized from microbial, lichen, and moss freeze-dried extracts incubated at 4°C for 40 days at two moisture levels.

live moss and lichen tissues, when desiccated and rewetted, release carbohydrates and organic nitrogen. These may become available to adjacent microbial and plant communities. Simon 1974 has suggested that such leakage is dependent on the degree of membrane integrity existing at the time of rewetting, for when membranes become fully hydrated, leakage virtually ceases. My study, in the main, used dead tissues. It is probable that leakage of soluble compounds from living mosses and lichens occurs in the field particularly during early thaw and first melt, although the magnitude of such leakage remains to be determined.

Water-extracts supported a vigorous microbial growth (visual observation) which resulted in the production of mineral-N (NH_4-N + NO_3-N).

Organisms			% TOTAL SAMPLE N NH_4-N $\bar{x}$ (range)	hexos-amine-N $\bar{x}$ (range)	amino- N $\bar{x}$ (range)	HUN* $\bar{x}$ (range)	acid insoluble N $\bar{x}$ (range)
Microbes[a]	n = 77		11 (9-14)	2 (1-4)	52 (49-54)	29 (22-35)	6 (3-12)
Lichens[a]	n = 24		10 (8-12)	8 (4-11)	46 (39-50)	26 (21-35)	10 (6-14)
Mosses[a]	n = 25		12 (9-13)	0	50 (48-51)	26 (23-28)	12 (10-14)
Cyanobacterial mats[b]		B	13 (11-15)	1 (0-1)	38 (35-39)	55 (49-61)	0
fresh	n = 8	A	17 (13-20)	1 (0)	52 (50-53)	27 (25-31)	3 (3-6)
Prasiola crispa[b]	n = 3	B	22 (19-25)	1 (0)	33 (31-34)	44 (40-48)	0
		A	23 (20-26)	1 (0)	50 (50-51)	18 (15-21)	7 (5-9)
Lichen composite[b]	n = 2	B	14 (13-15)	2 (1-2)	28 (22-35)	56 (53-59)	0
		A	16 (14-18)	3 (0)	50 (0)	27 (26-28)	4 (3-4)
Moss composite[b]	n = 2	B	8 (6-10)	0	27 (24-30)	65 (63-67)	0
		A	13 (0)	0	53 (0)	23 (22-24)	10 (9-11)

* HUN = hydrolysable unidentified nitrogen
[a] see Table 1
[b] see Table 4
B = before hydrolysis, A = after hydrolysis.

Table 6. Mean percentage nitrogen analyses and water soluble nitrogen substances of Antarctic biota.

The observation that lesser amounts of mineral-N were produced in moss and lichen extracts can be explained by the fact that these extracts contained larger amounts of carbon compounds, and had proportionally less organic nitrogen substances which resulted in a more prolonged immobilization of this nitrogen.

In general the use of freeze-thaw / wet-dry cycles did not markedly increase the amounts of water-soluble substances leached over and above those values obtained in the absence of these cycles. It may be possible to account for this in terms of cell wall structures and their permeability to water, which is considerably reduced if a waxy cuticle is present. Taylor & Parkinson (1988) have suggested that the number of freeze-thaw / wet-dry cycles to which whole tissues are subjected may be of importance in nutrient release and subsequent rates of decomposition. Fewer cycles would cause less damage to intact cells. In my study, only 5 cycles were attempted, whilst Taylor & Parkinson employed up to 84. It is not uncommon in Antarctica for terrestrial organisms to be subjected to several cycles each day (McKay & Friedmann 1985, Kappen & Friedmann 1983) so the use of only 5 cycles in this study must be regarded as unrealistic, particularly in the case of intact samples.

Regardless of sample fineness and the number of freeze-thaw / wet-dry cycles, it is clear that a variety of easily decomposable nutrients can enter Antarctic soil systems. The amounts entering soils, and the extent of their decomposition will depend to a large extent on the availability of free water.

In the Ross Dependency, the prevailing climate is dry and cold, but adjacent to glaciers and large snow drifts meltwater flows during the short growing season. Precipitation in the form of snow is very low, and fallen snow ablates within a few hours, with only transient amounts of free water. Many transient flows of meltwater are derived from small snow drifts; it is not uncommon to observe plant and microbial communities well removed from free water, and apparently moribund. My field observations over 10 years indicate that several of these communities have received only sporadic moisture derived entirely from light snowfall. The old cyanobacterial mats used in this study were derived from such communities and had undergone limited decomposition as judged by their brittle friable nature. Perhaps this, together with the lack of field leaching, is the reason why quite large amounts of water soluble sub-

stances were obtained from old mats in short or long term extractions. The water extracts from old cyanobacterial mats were just as susceptible to decomposition as were those extracts from fresh tissues (Table 5). Downes *et al.* (1986) suggested several sources for the organic matter occurring in streams in South Victoria Land, including allochthonous sources (wind blown or otherwise) derived from biota occurring on soils, dry stream beds and glaciers. This paper confirms and extends these authors' findings. Fresh and old cyanobacterial mats, cryoconite *Nostoc commune* and mosses all released substantial amounts of their mass when leached with water. The amounts removed in the field will largely depend on the volume of water (and hence duration and intensity of leaching), age and degree of intactness of any particular material, although quite large amounts of material can be released from intact tissues (Table 4). These water soluble substances (Table 5) are an important source of nutrients as well as energy for microbial growth and metabolism (Downes *et al.* 1986, Wynn-Williams 1986).

On maritime antarctic islands the prevailing climate is moist and cold and there is a more prolonged growing season (together with a greater species diversity and abundance) than in the Ross Dependency. Leaching processes occur on a much wider scale here than in the Ross Dependency although the soil communities in these areas probably experience a similar number of freeze-thaw / wet-dry cycles. The magnitude and extent of these cycles may be more pronounced under moist than dry conditions.

Tearle (1987) recorded soil moisture levels of 11-22% (dry-wt basis) at 0-1 cm depth, over spring and summer on Signy Island. Similar values prevail in the moister sites in the Ross Dependency, but soil moisture levels (at 0-5 cm) rarely exceed 5% in the more common drier soils (Greenfield unpublished, Boyd *et al.* 1966).

In the Ross Sea regions of continental Antarctica the prevailing climate is dry and cold. In what may be termed the active or growing season, arbitrarily regarded as late November until late January, less than 2 cm precipitation (entirely as snowfall) occurs, and atmospheric relative humidity is approximately 50% (range 8-97%) (Block 1985, Greenfield unpublished). Although air temperatures hover around 0°C, soil surface temperatures average about 6°C over this time at Cape Bird and the Garwood Valley (Greenfield & Wilson 1981, Greenfield 1983).

At Deception Island (Antarctic Peninsula) and Signy Island (South Orkney Islands) although similar air and soil temperatures prevail, relative humidity is constantly above 90% and approximately 12 cm precipitation (British Antarctic Survey Meterological data held at Signy station), predominantly rain, falls over the active growing season, arbitrarily regarded as late October until late March.

In summary, it appears that regardless of location in Antarctica, water soluble substances occur in the biota present on ahumic mineral soils. These substances will be released from killed, damaged or senescent cells at rates depending on the amounts of water present in these fellfield soils. The leachates contain microbial nutrients, utilization of which is profoundly affected by soil moisture content. Greenfield (1988) has shown that more mineral-N was produced when sandstone rocks containing Antarctic endolithic microbial communities were incubated at moisture levels greater than those commonly found in these rocks in the field. At Signy Island it is probable that large amounts of such leachates are metabolized in the moist soils during the growing season, whereas considerably less production and utilization of leachates occurs in the drier soils of Ross Island and the Dry Valleys. Such results are compatible with field observations and go some way in helping to understand the colonization of fellfield soils by micro and macro biota.

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